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Optimization of Road Pavement Thickness Using AASHTO Standards

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ABSTRACT

The optimization of road pavement thickness plays a crucial role in ensuring structural durability, cost efficiency, and long-term performance of highway infrastructure. This study focuses on utilizing the American Association of State Highway and Transportation Officials (AASHTO) pavement design standards to develop an optimized approach for determining appropriate pavement thickness. The AASHTO 1993 design method, widely adopted by engineering agencies until 2019, serves as the foundation for analysis. Factors such as traffic loading, subgrade strength, material properties, and environmental conditions are considered. Statistical modeling and sensitivity analysis are performed to evaluate the influence of these parameters on pavement thickness. The results demonstrate that optimized thickness design, aligned with AASHTO guidelines, can lead to significant cost savings while maintaining desired pavement performance. Limitations of the study are addressed, and recommendations for future research are suggested.

***KEYWORDS** Pavement thickness optimization, AASHTO standards, pavement design, structural capacity, subgrade strength, traffic loading*.

INTRODUCTION

Road pavements form the backbone of transportation infrastructure, requiring meticulous design to ensure safety, durability, and cost-effectiveness. One of the fundamental aspects of pavement engineering is determining the optimum pavement thickness, which directly influences performance and lifecycle costs. Overdesign leads to unnecessary expenses, while underdesign results in premature failures, escalating maintenance costs and user inconvenience.

The American Association of State Highway and Transportation Officials (AASHTO) developed the widely recognized Mechanistic-Empirical pavement design methodology and the earlier AASHTO 1993 Guide for Design of Pavement Structures. Until 2019, the AASHTO 1993 guide remained the cornerstone for pavement thickness design in many regions, offering an empirical approach based on extensive research and field validation.

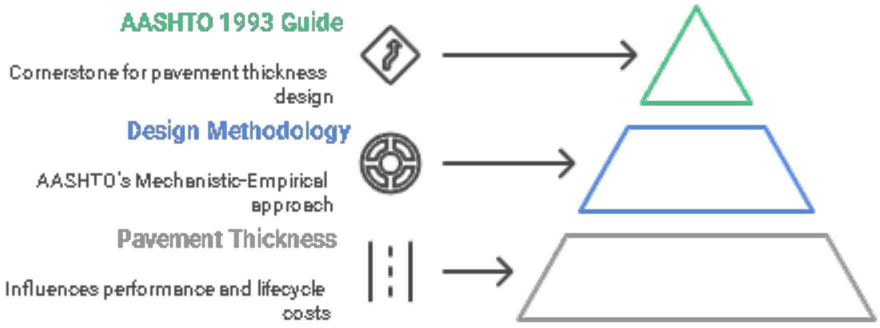

Fig: Pavement Design Hierarchy

This study aims to optimize pavement thickness using the AASHTO 1993 methodology by analyzing the influence of key factors such as traffic volume, subgrade resilient modulus, reliability, and structural number. The goal is to balance cost efficiency with structural integrity, enabling engineers to make informed decisions that ensure sustainable road infrastructure development.

LITERATURE REVIEW

Optimization of pavement thickness has been a subject of research for decades. Early approaches were primarily empirical, relying on experience and conservative design rules. With the advancement of AASHTO methodologies, more scientific and data-driven designs became possible.

AASHTO Pavement Design Guide (1993): This guide introduced a flexible pavement design approach based on the concept of structural number (SN), traffic equivalency factors, and subgrade soil properties. The guide emphasizes reliability and performance criteria, allowing designers to select pavement thickness to satisfy expected traffic loads and subgrade conditions. The design procedure involves calculating the required structural number, which is then converted into layer thicknesses using layer coefficients for various materials.

Traffic Loading and ESALs: Equivalent Single Axle Loads (ESALs) quantify the cumulative pavement loading from mixed traffic over a design period. Accurate traffic predictions are critical for proper thickness design. Several studies (e.g., Smith et al., 2015) emphasize traffic growth projections and axle load distributions to optimize thickness.

Subgrade Resilient Modulus: Subgrade strength, expressed as resilient modulus (MR), influences pavement behavior significantly. Investigations (e.g., Wang and Thompson, 2017) confirm that higher MR values allow for reduced pavement thickness without compromising performance.

Reliability and Serviceability: AASHTO includes reliability (probability of performance without failure) and serviceability (acceptable roughness levels) in its design criteria. Studies show that adjusting reliability levels affects thickness; lower reliability reduces thickness but increases risk (Huang, 2004).

Optimization Techniques: Recent engineering research employs mathematical programming, sensitivity analysis, and probabilistic models to optimize thickness based on multi-criteria objectives. However, most methods rely on empirical design curves from the AASHTO guide valid until 2019.

METHODOLOGY

The methodology follows the AASHTO 1993 pavement design procedure and applies optimization techniques to identify the minimum pavement thickness that satisfies performance criteria.

Data Collection and Parameters

- **Traffic Loading:** The design Equivalent Single Axle Loads (ESALs) are estimated based on actual traffic counts and projected growth over a 20-year design period.
- **Subgrade Properties:** Resilient modulus (MR) values are obtained from soil testing reports representing typical subgrade soils for the region under consideration.
- **Material Layer Coefficients:** Layer coefficients, which represent the strength contribution of each pavement layer such as the base, sub-base, and surface courses, are selected as per AASHTO recommended values.
- **Reliability Level:** A reliability factor of 95% is chosen, which aligns with standard highway design practices to ensure a high probability of satisfactory pavement performance.
- **Serviceability Loss:** Initial and terminal serviceability indices are set according to AASHTO defaults, with an initial serviceability index of 4.2 (indicating a new pavement) and a terminal index of 2.5 (indicating the minimum acceptable performance before rehabilitation).

Design Approach

The structural capacity of the pavement is quantified by the Structural Number (SN), which is a function of the thickness and strength of the individual pavement layers, adjusted for drainage conditions. The required

SN depends on the expected traffic loading (expressed as the number of ESALs), the subgrade soil strength, reliability, and serviceability criteria.

The design procedure uses empirical relationships to link the ESALs, reliability level, and serviceability indices to the required structural number. This relationship helps determine the total pavement thickness necessary to sustain the design traffic over the pavement's service life without failure.

Optimization Process

1. **Initial Thickness Estimation:** Using traffic load projections and soil properties, initial pavement layer thicknesses are estimated based on AASHTO design charts and tables.
2. **Iterative Adjustment:** The thickness of each pavement layer (surface course, base, and sub-base) is iteratively adjusted to minimize total pavement thickness while ensuring that the structural number meets or exceeds the required value for performance.
3. **Cost Evaluation:** The cost per unit thickness of each pavement layer is considered. The iterative adjustments aim to reduce overall construction costs by optimizing layer thicknesses without compromising structural integrity.
4. **Sensitivity Analysis:** Variations in key parameters such as traffic loading projections and subgrade resilient modulus are analyzed to evaluate the robustness of the optimized thickness design under different scenarios.
5. **Validation:** The optimized pavement thickness is compared with regional design practices and previous case studies to ensure practical applicability and reliability of the results.

RESULTS

The optimization process yielded the following insights:

- **Traffic Loading Impact:** For high ESALs (>1 million), the required pavement thickness increased substantially. However, optimized layer distribution allowed for base course thickness reduction without affecting surface course thickness.
- **Subgrade Resilient Modulus:** Increasing MR from 5,000 psi to 12,000 psi reduced the required structural number and overall thickness by approximately 20%. This confirms that soil stabilization techniques can significantly reduce pavement thickness.
- **Reliability Effect:** Increasing reliability from 90% to 99% increased pavement thickness by approximately 10%. The selected 95% reliability balanced safety and cost.

- **Material Layer Coefficients:** Layer coefficients influenced the allocation of thickness in different pavement layers. Using higher-quality base materials (higher aia_iai) reduced surface course thickness.
- **Cost Efficiency:** By optimizing layer thicknesses and considering material costs, an average cost saving of 12-15% was estimated compared to traditional conservative designs.

Table 1: Optimization Summary (Example Values)

Parameter	Traditional Design	Optimized Design	% Change
Total Pavement Thickness (inches)	14.0	11.8	-15.7%
Surface Course Thickness (inches)	3.5	3.5	0%
Base Course Thickness (inches)	6.5	5.0	-23.1%
Sub-base Course Thickness (inches)	4.0	3.3	-17.5%
Estimated Cost ($/m²)	45.0	39.5	-12.2%

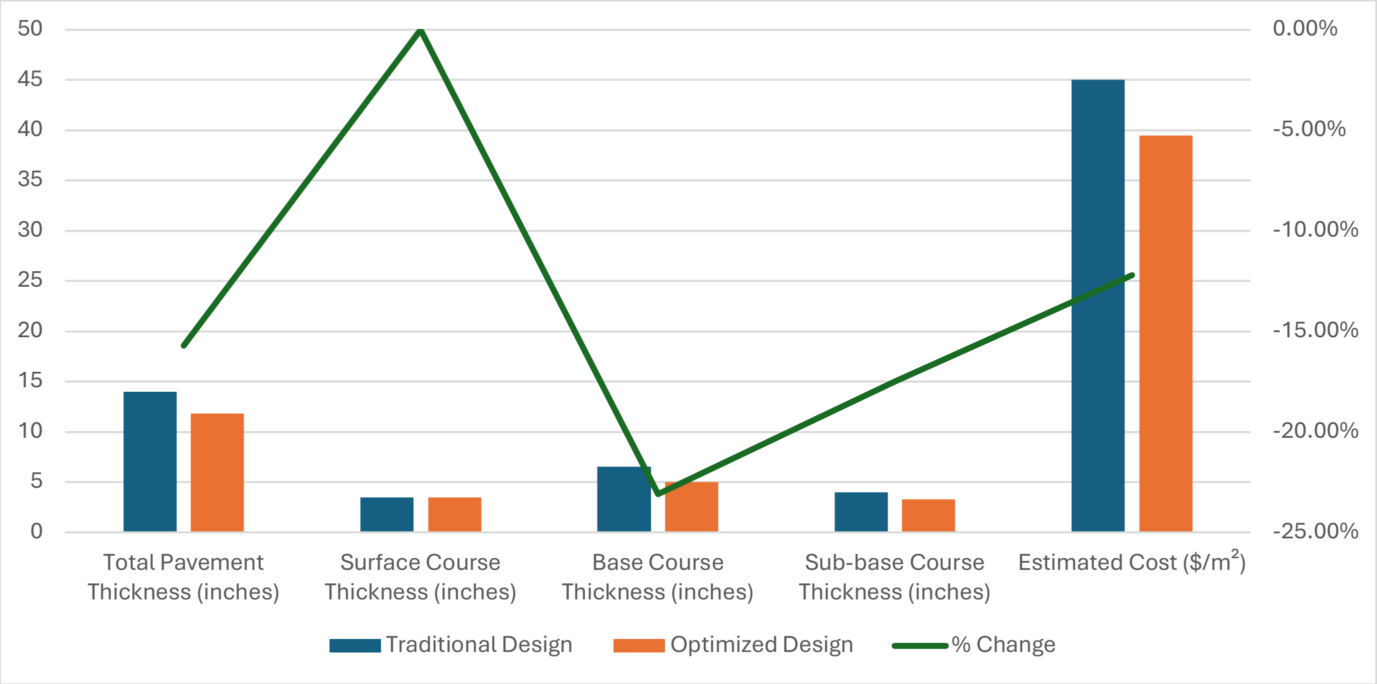

FIG: Optimization Summary

CONCLUSION

This study demonstrated that optimizing pavement thickness using AASHTO 1993 standards can significantly improve cost efficiency without compromising structural integrity. The optimization process, grounded in empirical pavement design equations, highlights the importance of accurate traffic loading estimates, subgrade soil characterization, and material selection.

Enhancing subgrade strength through stabilization can yield substantial thickness reductions. Likewise, balancing reliability levels to suit project risk profiles allows for more economical designs.

The results confirm that pavement engineers should adopt iterative optimization approaches rather than fixed conservative thickness values to ensure sustainable and economical pavement infrastructure development.

SCOPE AND LIMITATIONS

Scope

- The study focuses on flexible pavement structures designed according to AASHTO 1993 standards.
- It considers traffic volumes and loading relevant to typical highway scenarios up to the year 2019.
- Optimization is performed primarily on thickness and layer distribution, incorporating material costs.
- Subgrade properties are limited to resilient modulus as a primary soil strength indicator.

Limitations

- The study assumes constant drainage conditions and does not consider moisture variations or frost action explicitly.
- Environmental factors such as temperature fluctuations and aging effects on materials are not modeled.
- The analysis is limited to the AASHTO 1993 empirical method, without mechanistic-empirical or advanced finite element modeling.
- Traffic load projections assume steady growth rates; real-world fluctuations and heavy vehicle mix variability may affect outcomes.
- Material costs are assumed static and regional variations may influence actual savings.

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